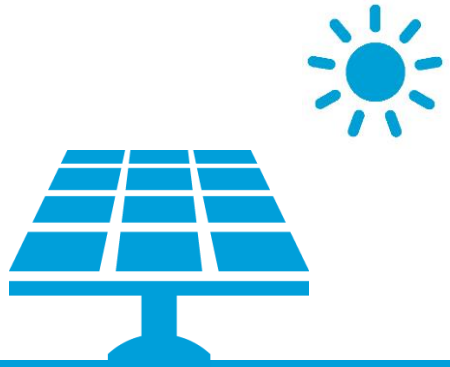
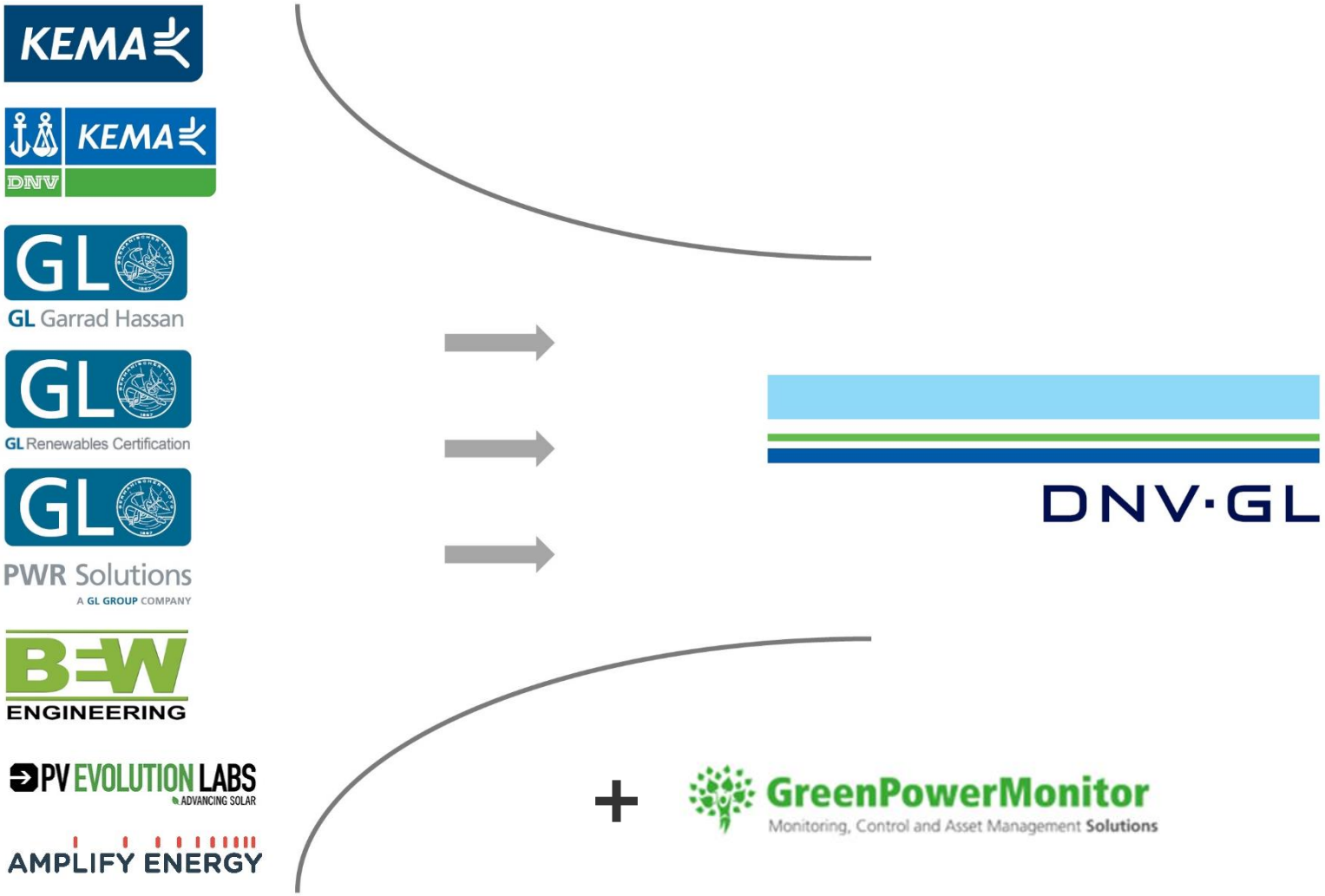
DNV·GL



PV Equipment Testing: Historical Data and Best Practices for Product Qualification

Combined strength to support Energy customers



Confidential

About DNV GL

150 years

350 offices

14,000 employees

100 countries

DNV GL is the world's largest independent energy & renewables advisory firm.

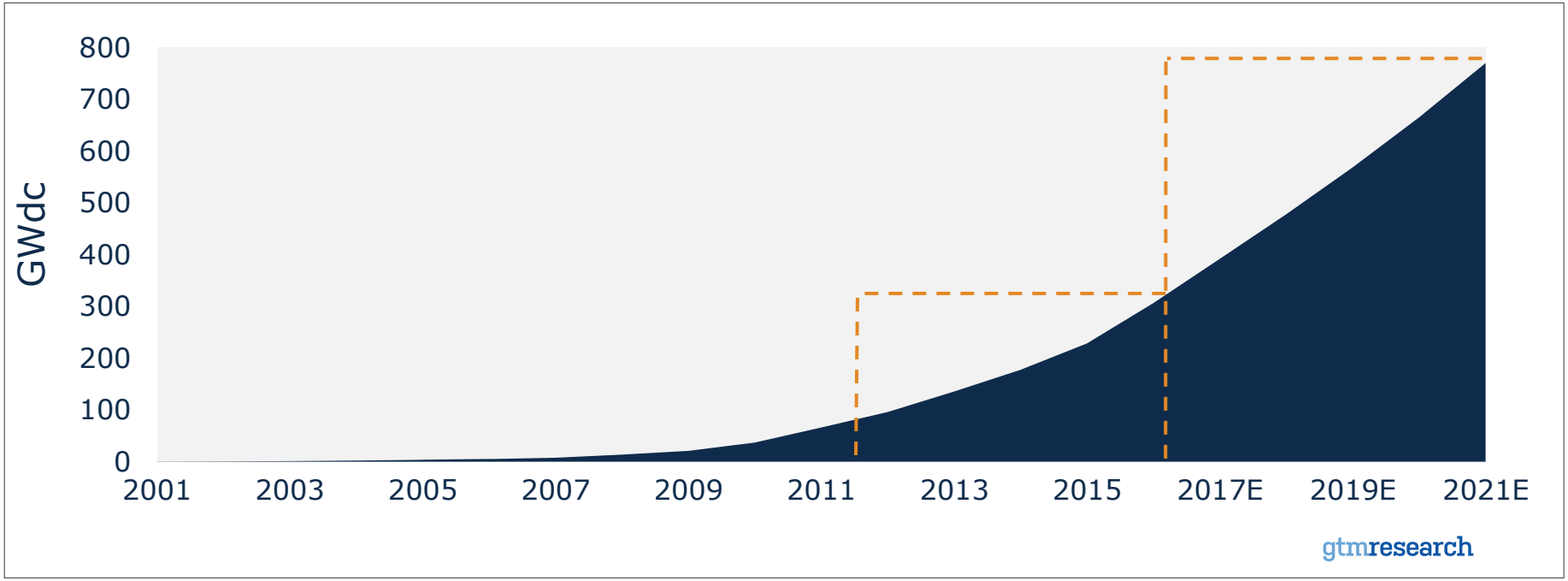
We have over 2500 energy experts.

More than 1000 are focused on renewables.

DNV GL has advised over 5500 solar projects.

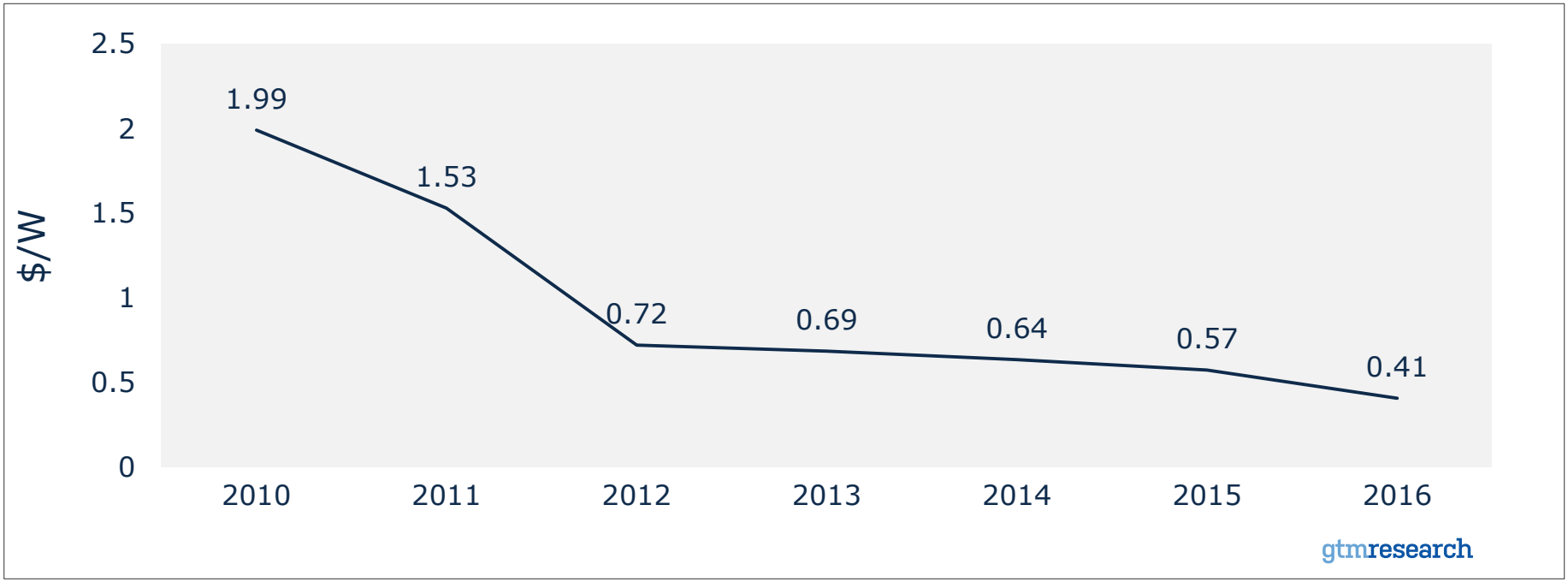
Extensive experience in solar technology and applications.

Cumulative installed global PV capacity



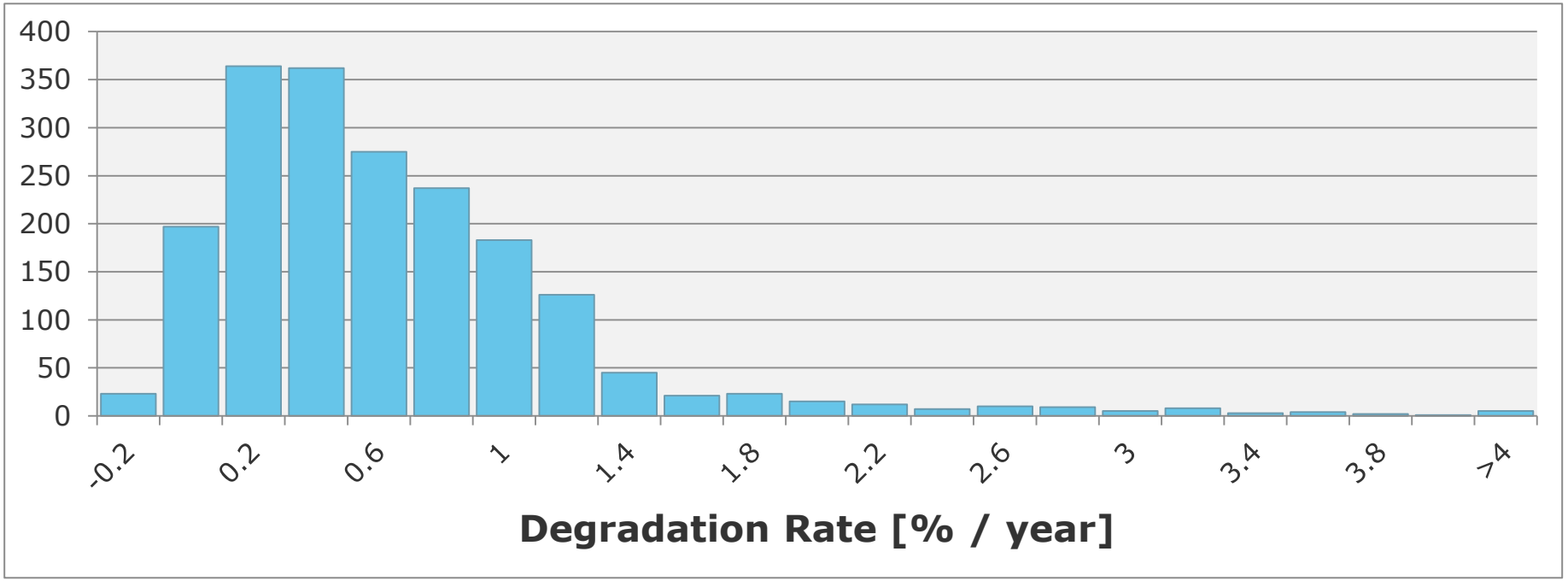
- 78% of installed capacity deployed in past 5 years
- Depolyments expected to increase 2.5x in the next 5 years

Global blended module price



- ~80% drop in module price since 2010
- ~30-50% (!) drop since early 2016

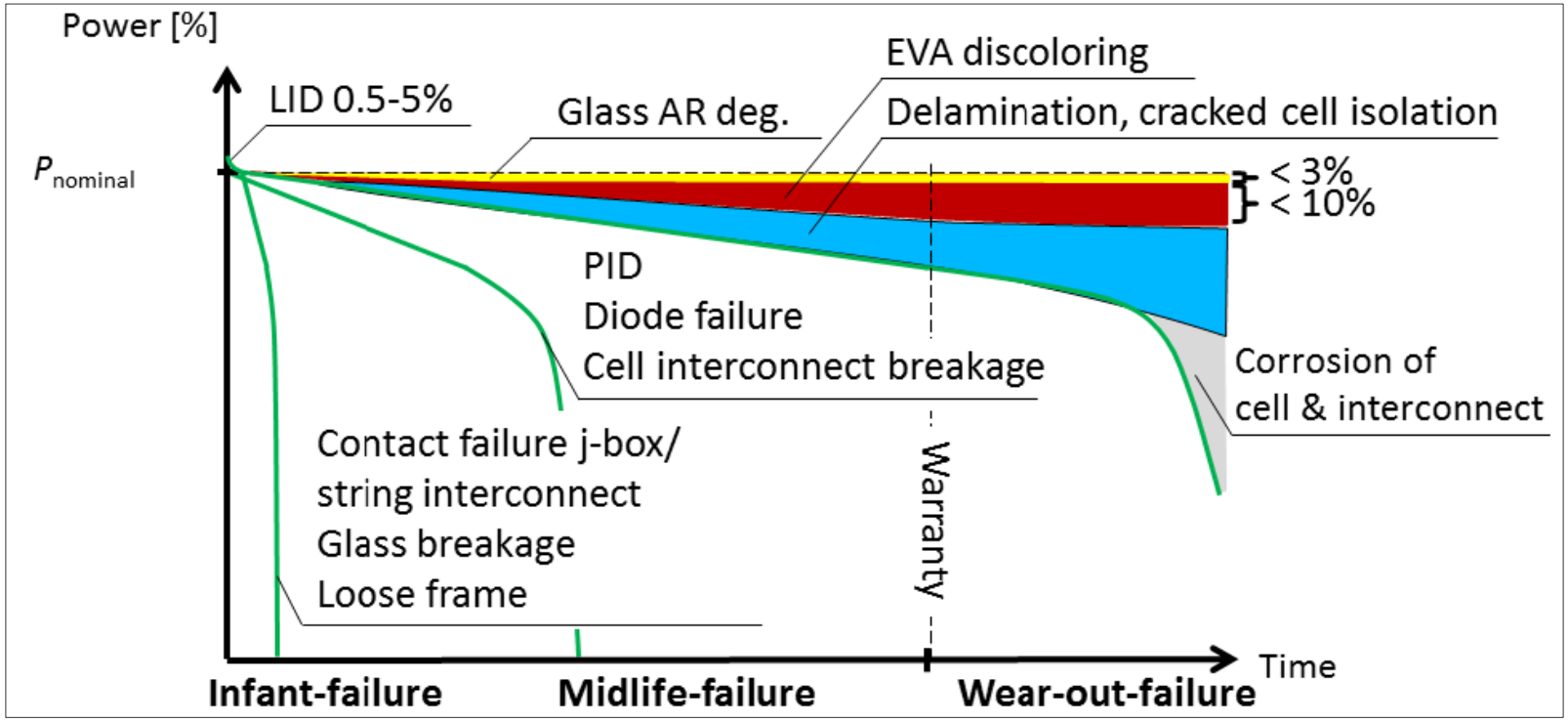
NREL Degradation Study "High Quality" Dataset



Mean degradation rate	Median degradation rate	P90 degradation rate
0.5 – 0.6 % / year	0.4 – 0.5 % / year	1.2 % / year

"Compendium of Photovoltaic Degradation Rates", D.C. Jordan, et al, NREL, 2015

Aging mechanisms leading to PV module degradation



- Solder joints / internal circuit recurring failure mechanism

- *Review of Failures of Photovoltaic Modules*, IEA PVPS 2014

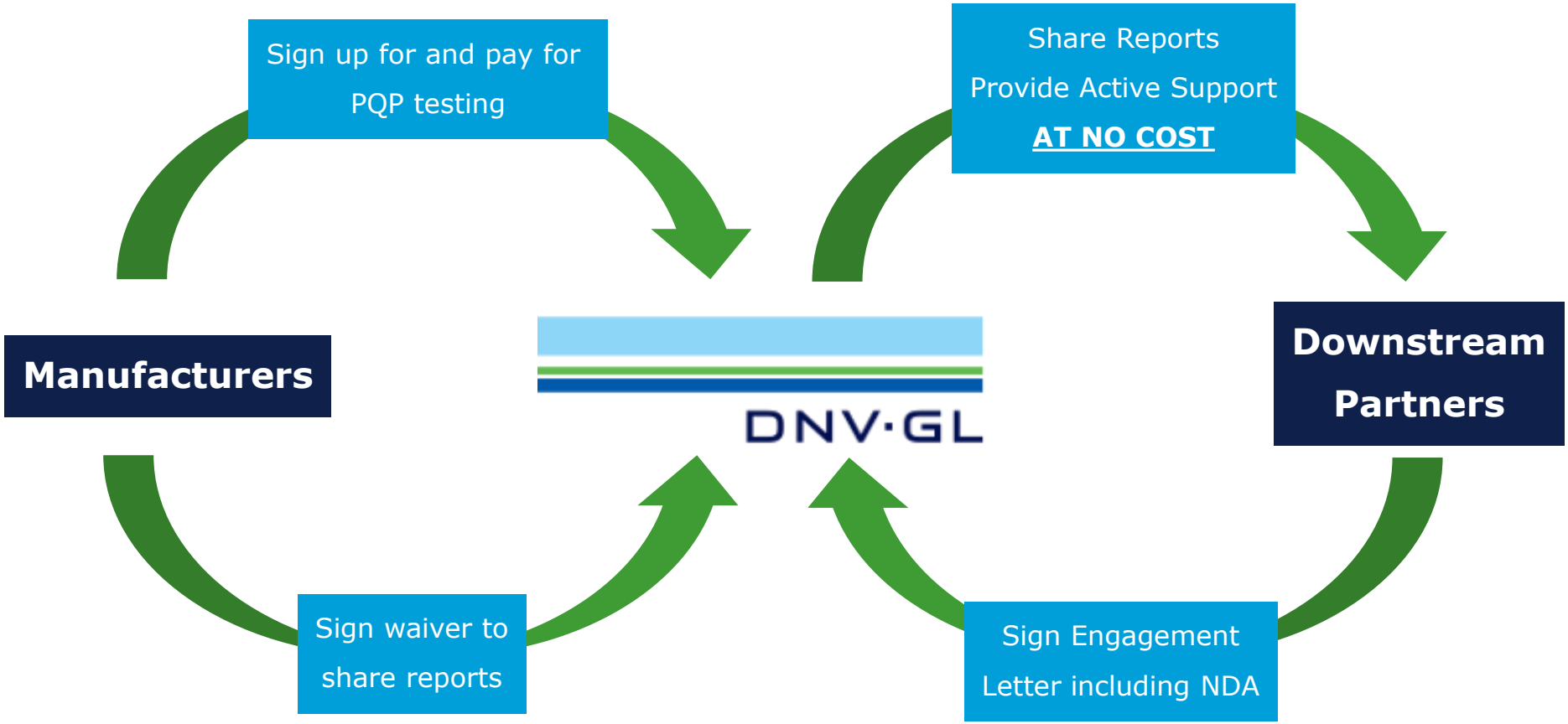
DNV GL Component Testing Services

1. **Product Qualification Program:** downstream partners obtain data / reports at zero cost. Support for managing Approved Vendor List or RFP invites

PV Modules	PV Inverters	Energy Storage
■ Testing for BOM ■ Extended Reliability Testing ■ Performance Testing – PAN Files – IAM coefficients – LID – NOCT	■ Reliability Testing ■ Envelope Characterization ■ Transient Response ■ Low Light Peformance ■ Efficiency ■ Arc / ground fault ■ Micro, string, and utility scale ■ AFCI nuisance trip	■ Round Trip Efficiency ■ Self-Discharge ■ Response Time & Ramp Rate ■ Overvoltage / undervoltage Protection ■ SOC Validation ■ Full System Cycle Testing ■ Environmental Testing ■ Cell Level Testing

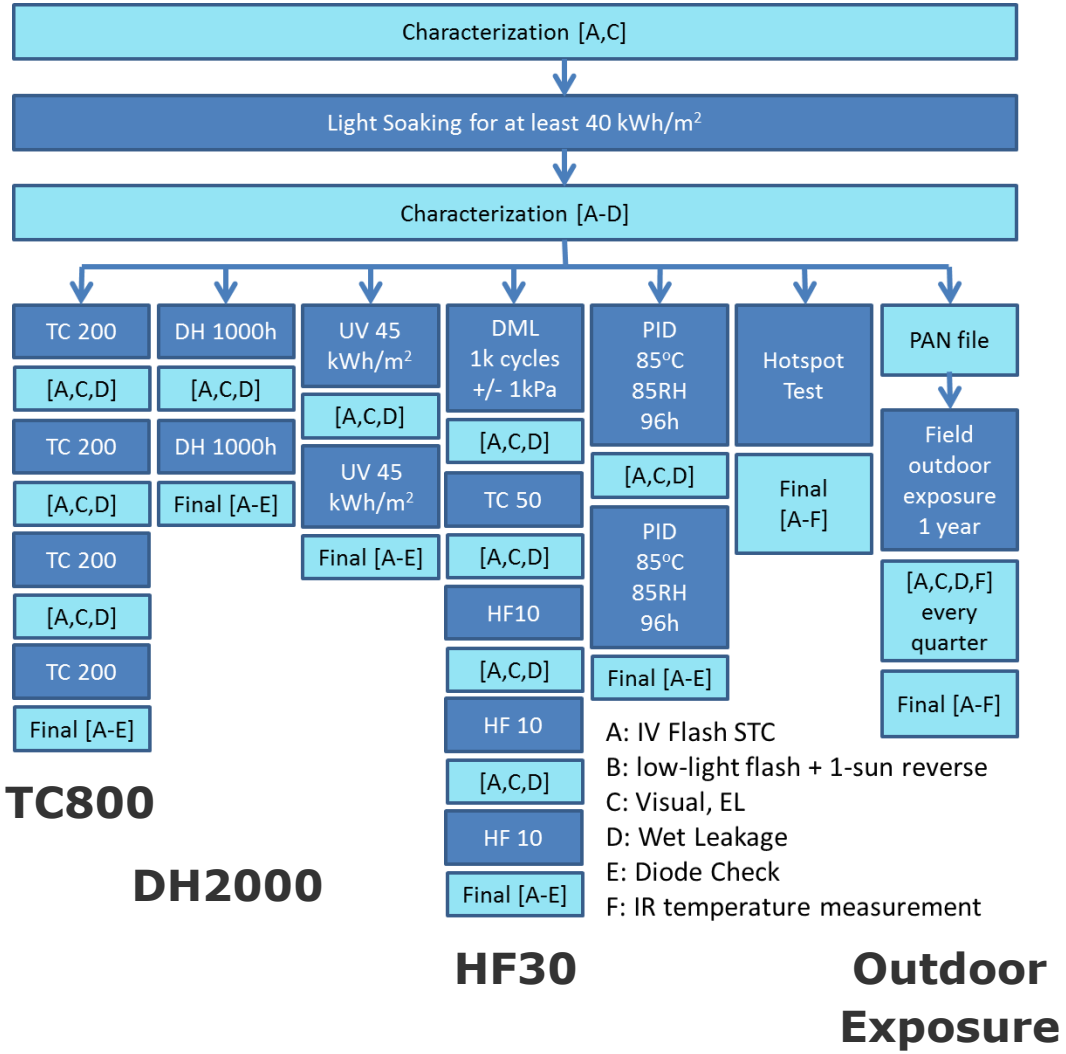
2. **Statistical Batch Testing:** Statistical testing at the project by project level to screen for defects and to verify that you got what you paid for

Product Qualification Program (PQP) – At a Glance

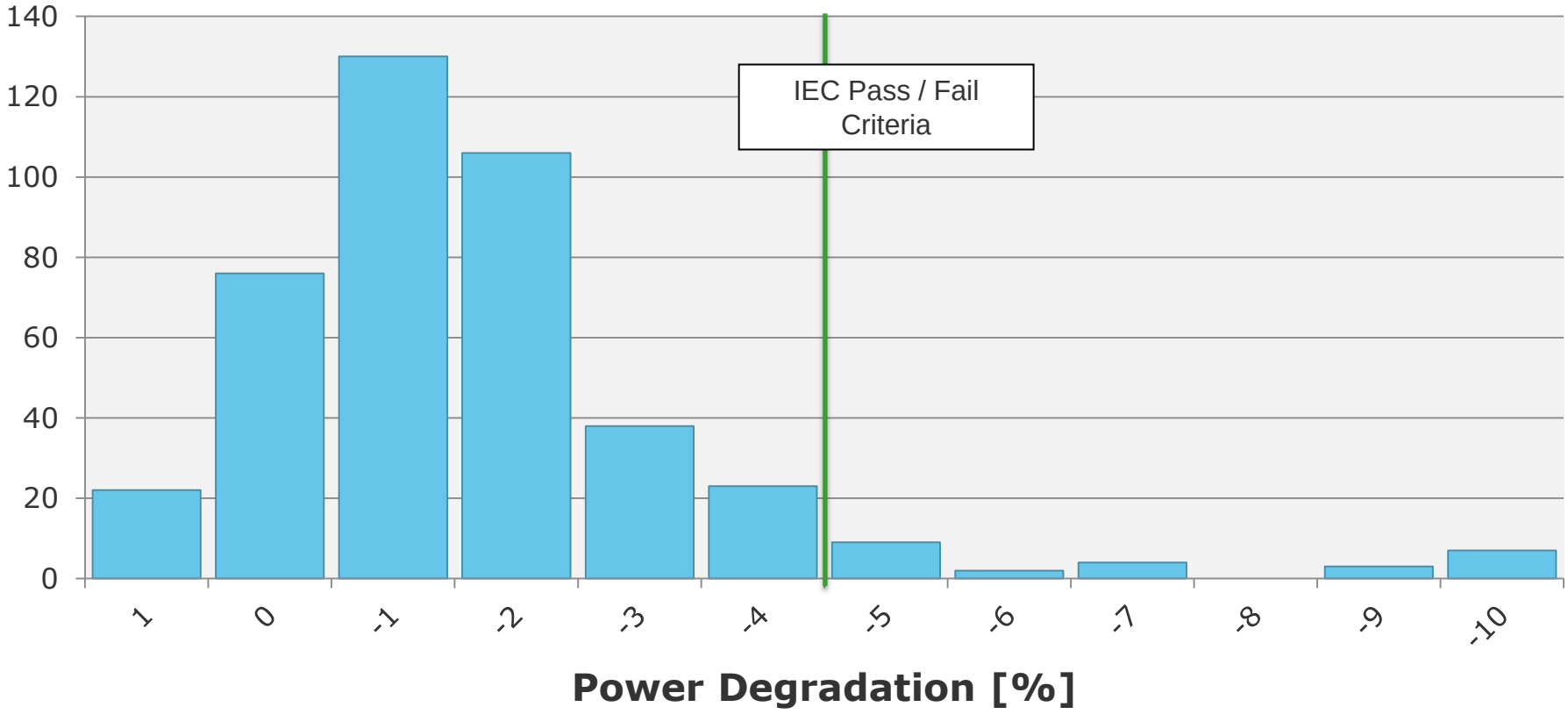


MODULE PRODUCT QUALIFICATION PROGRAM

- Testing per BOM
- Independent witness of build to ensure no "golden samples"



Thermal Cycling (200 cycles) Results from DNV GL Labs

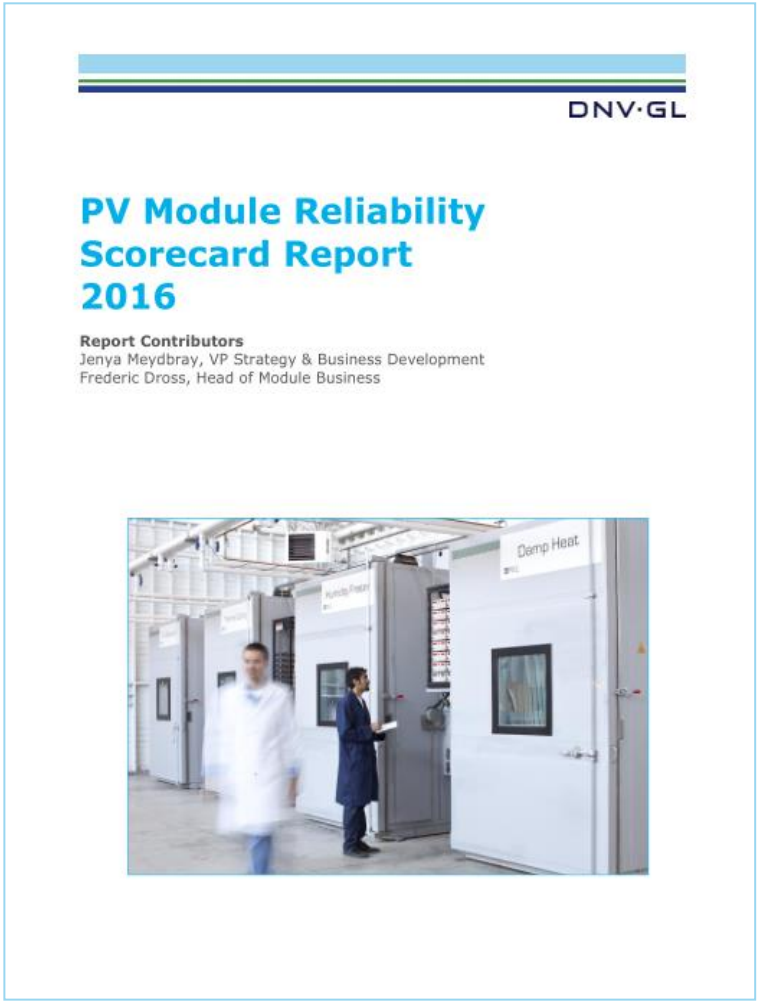


- 6% of commercially available modules don't meet IEC certification criteria

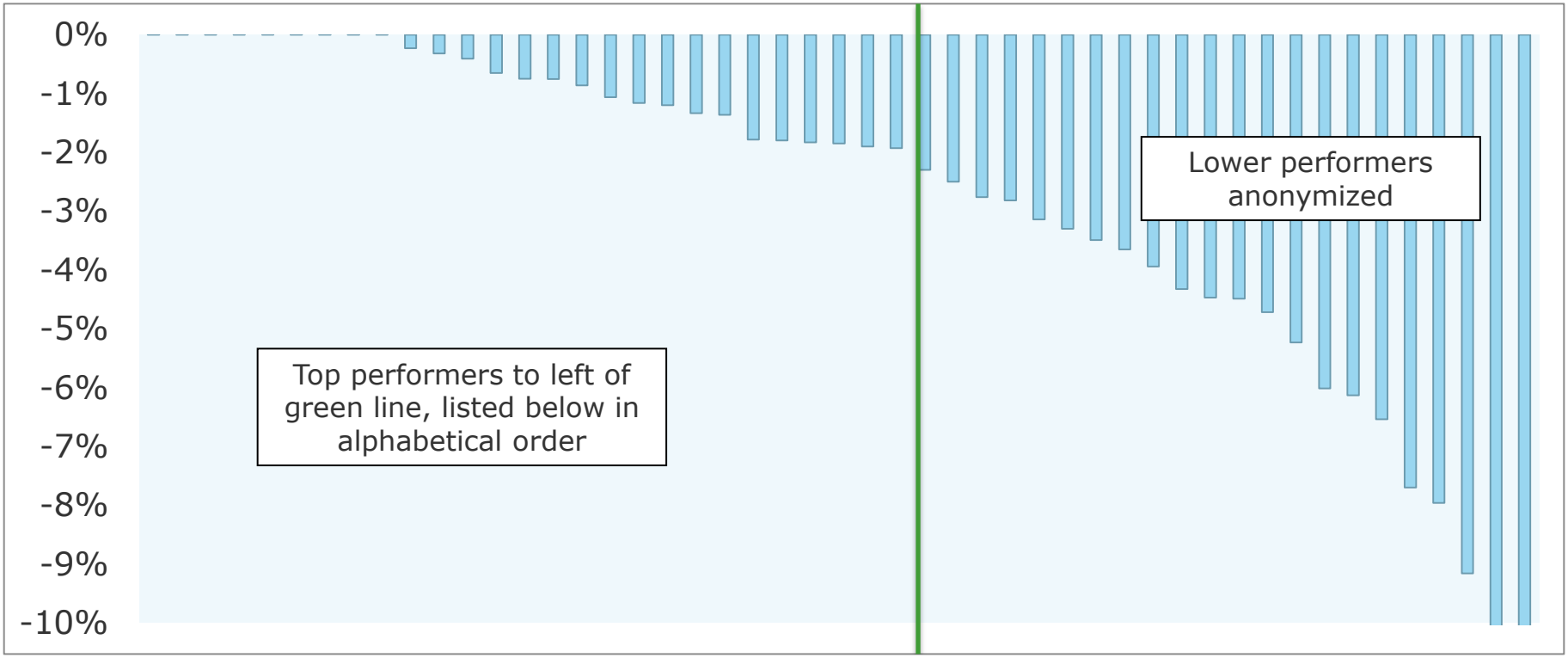
Scorecard

- Using the qualification program data we have released the **PV module reliability scorecard** – Free download on the DNV GL website
- Report contains high level test results – details are available to downstream partners – *BOM and factory location is critical*

- **Inverter qualification scorecard** coming in 2017

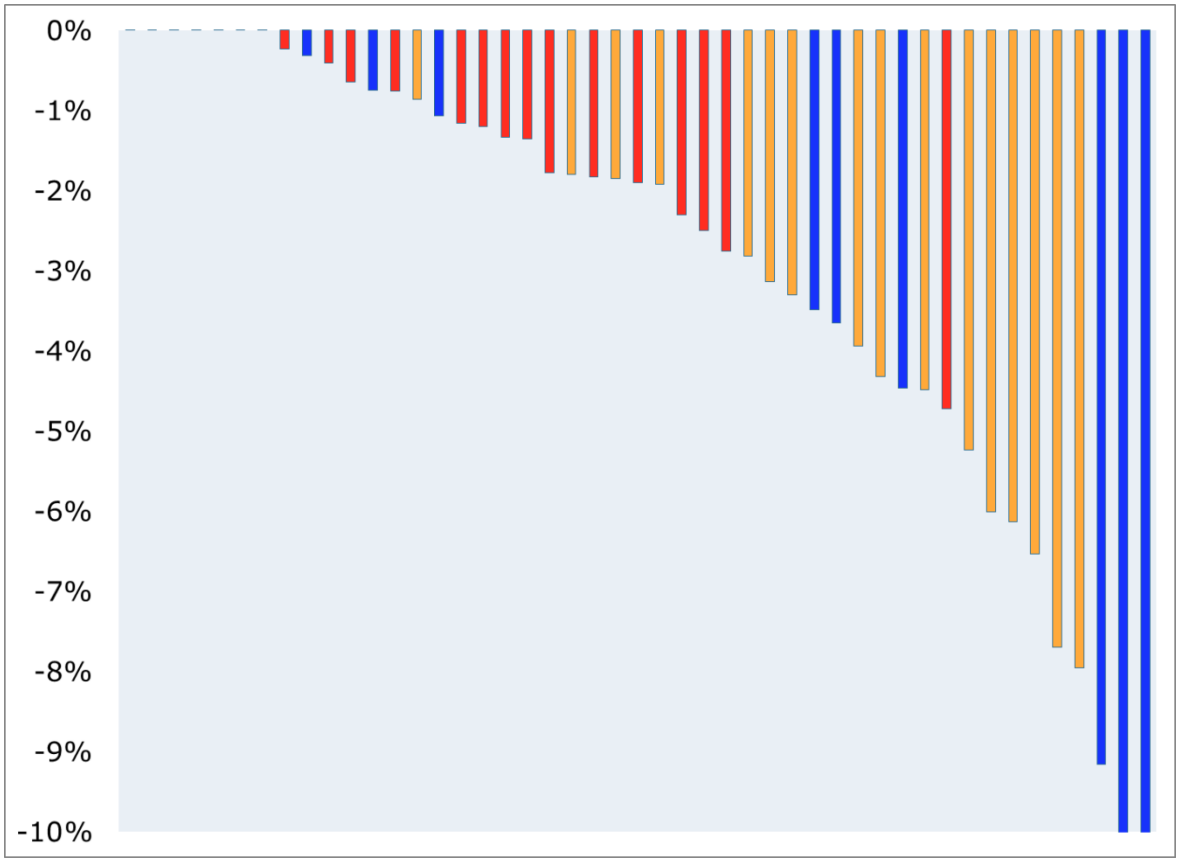


Thermal Cycling (600 cycles)



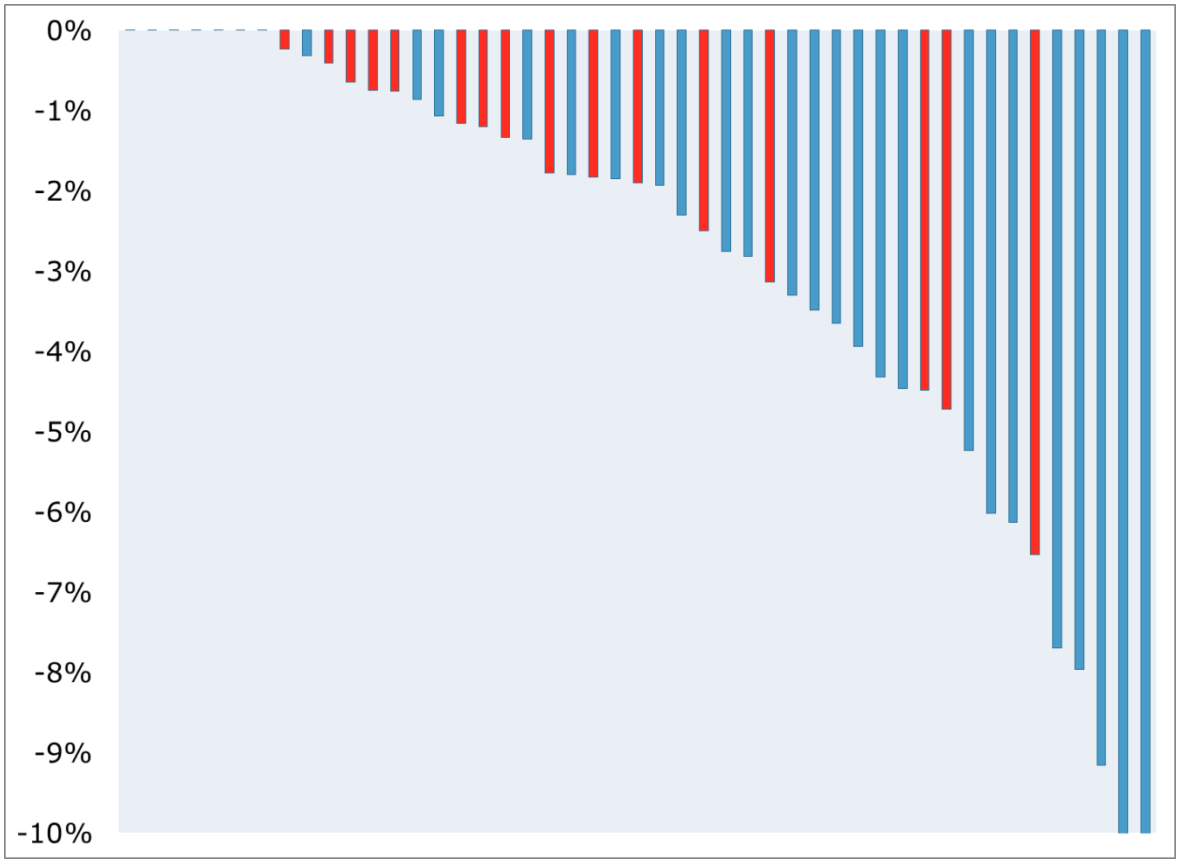
- 22 manufacturers across 40 module models with 49 unique BOMs participated

Thermal Cycling (600 cycles): Country of Production



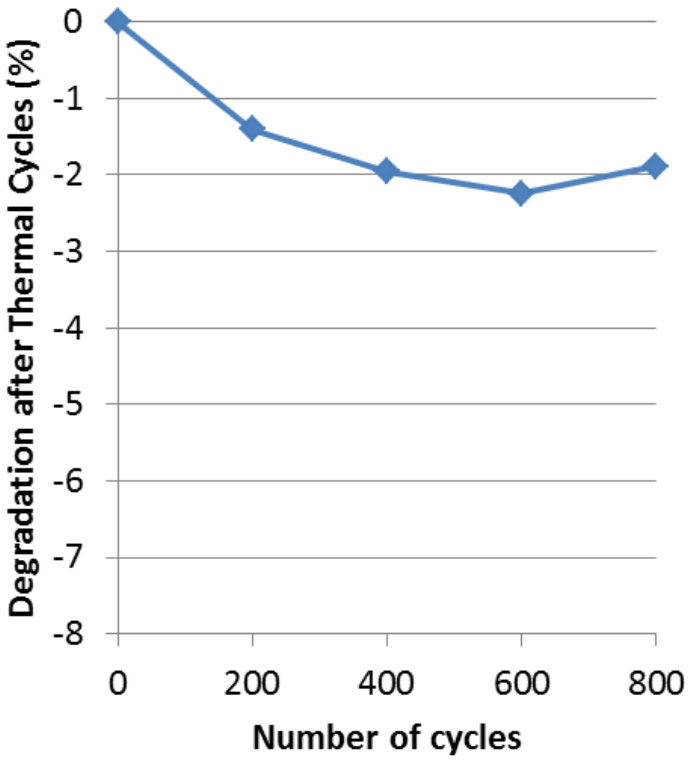
- RED: China
- YELLOW: Asia
- BLUE: ROW

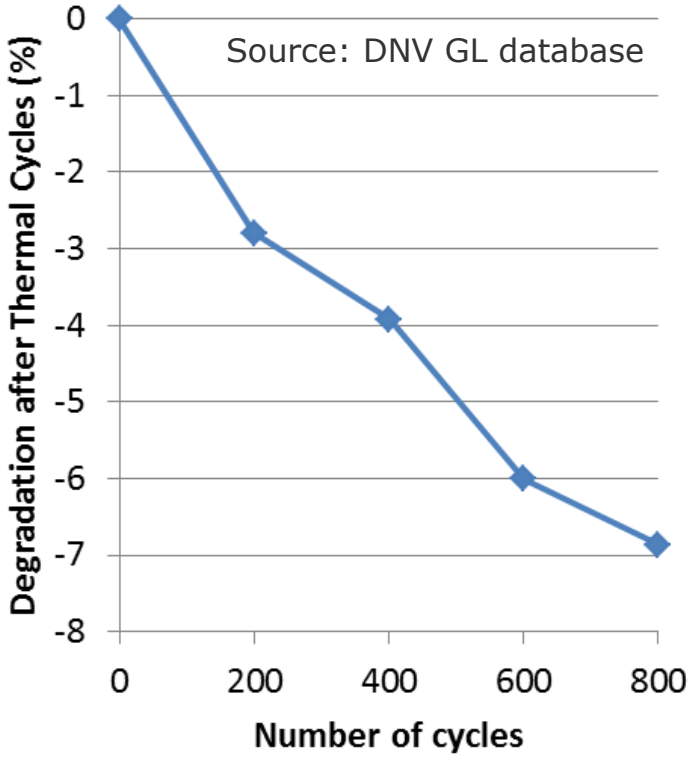
Thermal Cycling (600 cycles): Manufacturer Size



- RED: Top 10 largest by shipment volume
- BLUE: other

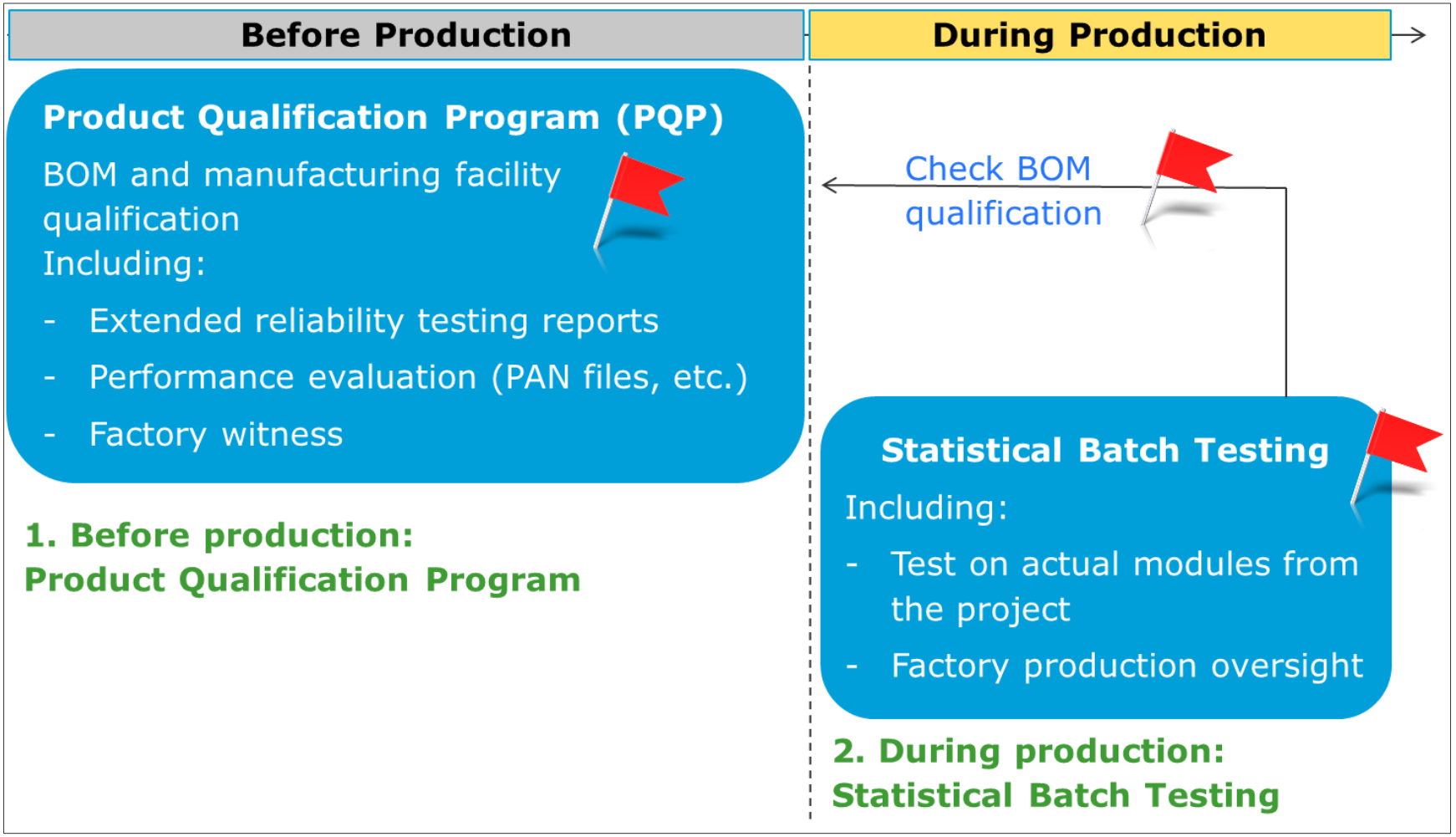
Module types may have very different bill-of-materials





- **Same module type – Different bill of material**
- DNV GL defines one BOM with 107 parameters (EVA, backsheet, etc.)
- Factory location is one element of the BOM

Recommended Procedure to Assess Module Risk



Thank you.

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SAFER, SMARTER, GREENER

